

The dynamical intracluster medium: a combined approach of observations and simulations

Elke Roediger*, Marcus Brüggen*, Aurora Simionescu†, Hans Böhringer†
and Sebastian Heinz**

*Jacobs University Bremen, PO Box 750 561, 28725 Bremen, Germany

†Max-Planck-Institute for Extraterrestrial Physics, Giessenbachstr, 85748, Garching, Germany

**Department of Astronomy, University of Wisconsin, 475 N Charter Street Madison, WI 53706,
USA

Abstract. Current high resolution observations of galaxy clusters reveal a dynamical intracluster medium (ICM). The wealth of structures includes signatures of interactions between active galactic nuclei (AGN) and the ICM, such as cavities and shocks, as well as signatures of bulk motions, e.g. cold fronts. Aiming at understanding the physics of the ICM, we study individual clusters by both, deep high resolution observations and numerical simulations which include processes suspected to be at work, and aim at reproducing the observed properties. By comparing observations and simulations in detail, we gain deeper insights into cluster properties and processes. Here we present two examples of our approach: the large-scale shock in the Hydra A cluster, and sloshing cold fronts.

Keywords: galaxy clusters – ICM – AGN

PACS: 98.54.Cm; 98.65.Cw, 98.65.Hb

THE LARGE-SCALE SHOCK IN HYDRA A

The galaxy cluster Hydra A is well-known for its AGN activity, evident not only in a pair, but a whole set of X-ray cavities (McNamara et al. 1, Nulsen et al. 2, 3, Wise et al. 4). Moreover, Nulsen et al. [3] and Wise et al. [4] detected a large-scale (~ 400 kpc) surface brightness discontinuity encircling the largest pair of cavities (Fig. 1, left panel). These authors interpreted the surface discontinuity as a shock caused by the same AGN outbreak that created the largest pair of X-ray cavities. However, the temperature jump that should be associated with such a shock was not yet detected.

Observations

We analyzed a new deep XMM-Newton observation of Hydra A, focusing on the large-scale shock described above (Simionescu et al. 6). The shock front can be seen, both, in the pressure map and in temperature profiles (Fig. 1, right panel). Thus, we can confirm the shock nature of the surface brightness discontinuity. The Mach number of the shock inferred in several sectors is ~ 1.3 . The shape of the shock can be approximated with an ellipse centered ~ 70 kpc towards the NE from the cluster center. In addition to this offset, the northern radio lobes appear larger than the southern ones.

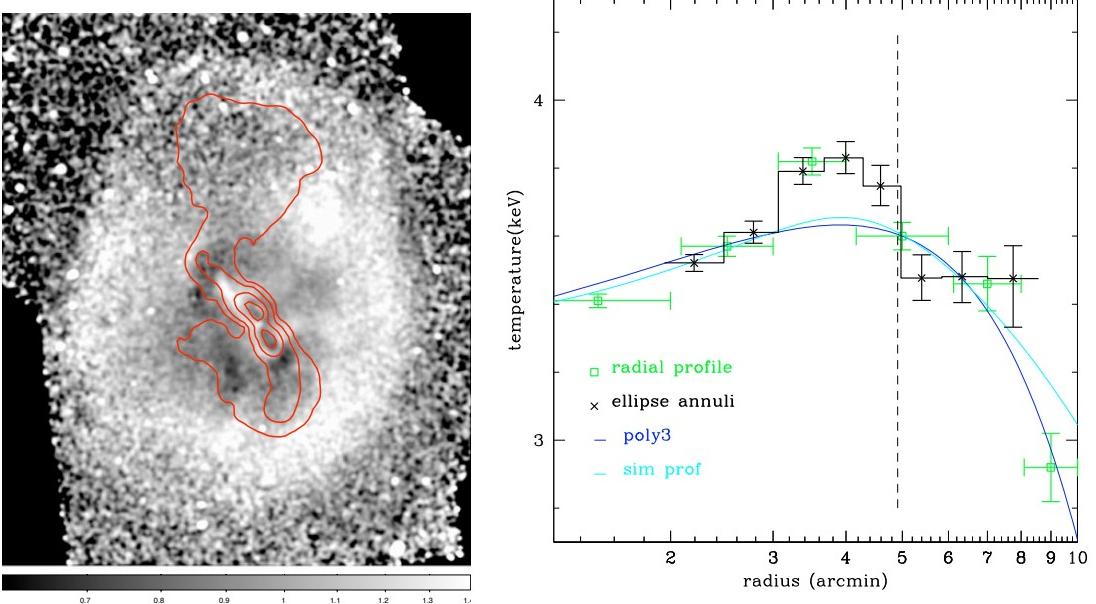


FIGURE 1. Hydra A observed. Left: residual X-ray image (background, A. Simionescu) and radio contours (Lane et al. 5). Right: Temperature profile in spherical or elliptical annuli, from Simionescu et al. 6. The vertical dashed line marks the shock.

Simulations

If the AGN interacts with a dynamical ICM, e.g. a large-scale bulk flow, the resulting structure - the combination of radio lobes, cavities, and shock - could display the observed asymmetry and offset. We explore this scenario by means of 3D hydrodynamical simulations (Simionescu et al. 6). The shock is produced by a symmetrical pair of AGN jets launched in a spherical galaxy cluster. The simulation successfully reproduces the size, ellipticity, and average Mach number of the observed shock front. The predicted age of the shock is 160 Myr and the total input energy 3×10^{61} erg. To match the observed 70 kpc offset of the shock ellipse by large-scale coherent motions, these would need to have a high velocity of 670 km s^{-1} . Although this scenario can explain the overall structure (Fig. 2), the required velocity is rather high. Alternative scenarios include a motion of the AGN w.r.t. the ICM, a non-spherical cluster structure, or a combination of different effects.

COLD FRONTS

In recent years, cold fronts have been detected in many clusters (see review by Markevitch and Vikhlinin 7 and references therein). They become evident as surface brightness discontinuities, where, in contrast to shocks, the brighter side is the cooler one. The discontinuities in surface brightness, temperature and density tend to very sharp. The pressure is approximately continuous over the front. Besides cold fronts associated with

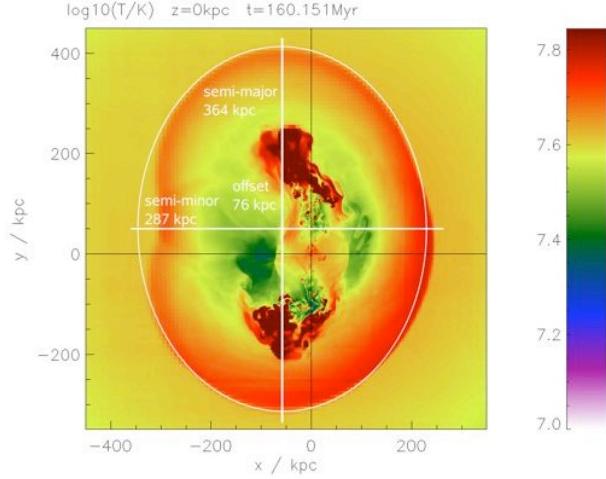


FIGURE 2. Hydra A simulated: Slice through the computational grid, color-coding shows temperature (from Simionescu et al. 6).

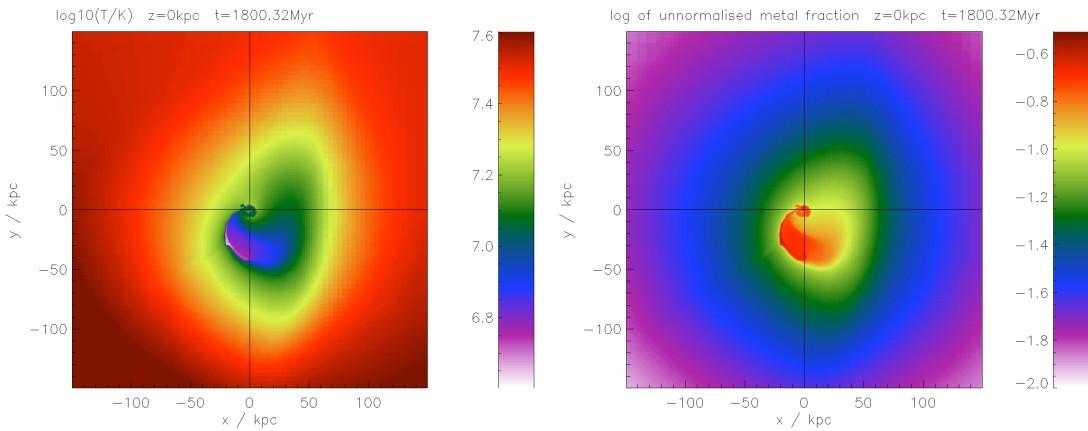


FIGURE 3. Cold front in a Virgo-like cluster: slice through the computational grid, color-coding shows temperature (left) and unnormalised metal fraction (right).

obviously merging clusters, another, somewhat weaker, variety has been detected to be "wrapped" around the cores of many otherwise relaxed and cool core clusters (Ghizzardi et al. 8, 9). The best-fit scenario available so far to explain these cold fronts is the idea of ICM sloshing, where a subcluster or, in best case, a dark matter only substructure passes near the cluster core, offsets the ICM, which then sloshes inside the cluster potential (Markevitch et al. 10, Ascasibar and Markevitch 11). Recently, also discontinuities in metallicity associated with such cold fronts have been observed (e.g. Fabian et al. 12, Dupke et al. 13), providing additional constraints on models.

We have run high resolution 3D hydrodynamical simulations of the sloshing scenario (Roediger et al. in prep.) which also trace the metal distribution in the ICM. These simulations can produce both, temperature and metallicity discontinuities (Fig. 3). We

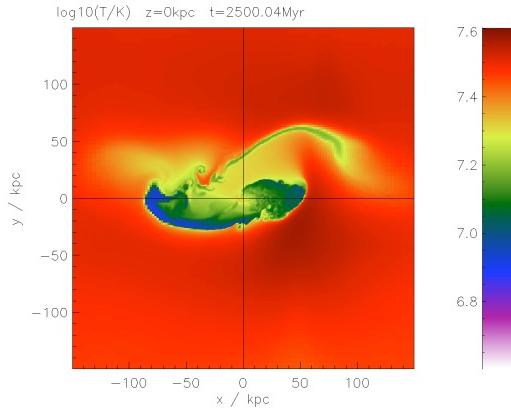


FIGURE 4. Cold front in an elliptical Virgo-like cluster: slice through the computational grid, color-coding shows temperature. Note the elongated shape of the cold front.

apply this model to observed clusters to verify or disprove the sloshing scenario for them. For this purpose, we model ICM sloshing in both, spherical and elliptical clusters, and study the influence of cluster shape on the structure of the cold fronts.

ACKNOWLEDGMENTS

We acknowledge the support of the Priority Programme “Witnesses of Cosmic History” of the DFG (German Research Foundation) and the supercomputing grant NIC 2195 at the John-Neumann Institut at the Forschungszentrum Jülich. The results presented were produced using the FLASH code, a product of the DOE ASC/Alliances-funded Center for Astrophysical Thermonuclear Flashes at the University of Chicago.

REFERENCES

1. B. R. McNamara, M. Wise, P. E. J. Nulsen, L. P. David, C. L. Sarazin, M. Bautz, M. Markevitch, A. Vikhlinin, W. R. Forman, C. Jones, and D. E. Harris, *ApJ* **534**, L135 (2000).
2. P. E. J. Nulsen, L. P. David, B. R. McNamara, C. Jones, W. R. Forman, and M. Wise, *ApJ* **568**, 163 (2002).
3. P. E. J. Nulsen, B. R. McNamara, M. W. Wise, and L. P. David, *ApJ* **628**, 629 (2005).
4. M. W. Wise, B. R. McNamara, P. E. J. Nulsen, J. C. Houck, and L. P. David, *ApJ* **659**, 1153 (2007).
5. W. M. Lane, T. E. Clarke, G. B. Taylor, R. A. Perley, and N. E. Kassim, *AJ* **127**, 48 (2004).
6. A. Simionescu, E. Roediger, P. E. J. Nulsen, M. Brüggen, W. R. Forman, H. Böhringer, N. Werner, and A. Finoguenov, *A&A* **495**, 721 (2009).
7. M. Markevitch, and A. Vikhlinin, *Physics Reports* **443**, 1 (2007).
8. S. Ghizzardi, S. Molendi, A. Leccardi, and M. Rossetti, *Proceedings of the The X-ray Universe 2005 (ESA SP-604). 26-30 September 2005* **604**, 717 (2006).
9. S. Ghizzardi, S. Molendi, M. Rossetti, and A. Leccardi, *Heating versus Cooling in Galaxies and Clusters of Galaxies* p. 33 (2007).
10. M. Markevitch, A. Vikhlinin, and P. Mazzotta, *ApJ* **562**, L153 (2001).
11. Y. Ascasibar, and M. Markevitch, *ApJ* **650**, 102 (2006).
12. A. C. Fabian, J. S. Sanders, G. B. Taylor, and S. W. Allen, *MNRAS* **360**, L20 (2005).
13. R. Dupke, R. E. White, and J. N. Bregman, *ApJ* **671**, 181 (2007).